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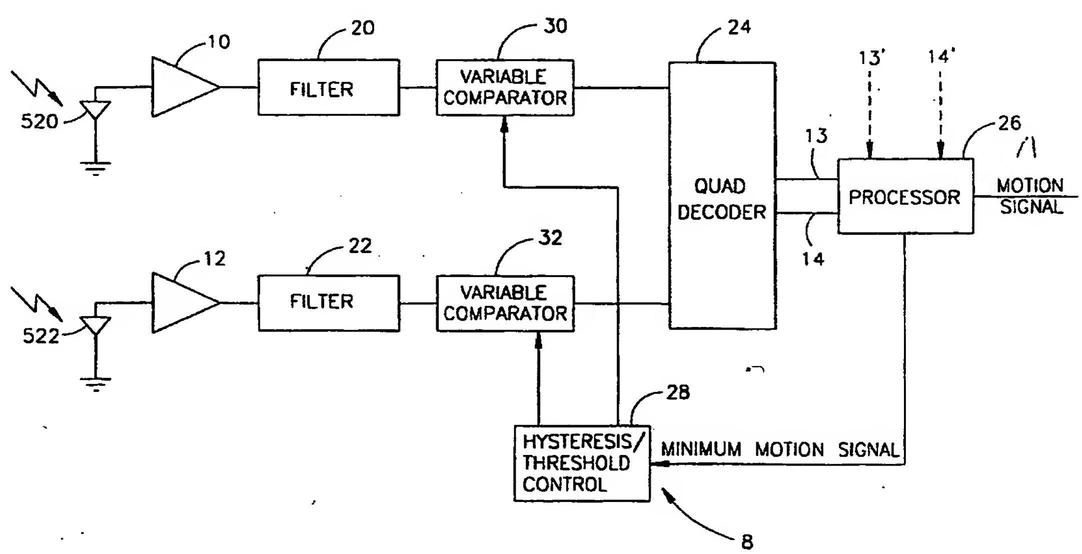

(57) Abstract: A polarizing beam splitter for radiation having a wavelength, comprising: a series of first regions having a first effective index of refraction for a first polarization direction and a second effective index of refraction, different from the first index of refraction for a second polarization direction; and a series of second regions, interleaved with the regions of the first series of regions, said second regions having an effective index for at least one polarization direction different from that of the first regions for the same polarization direction.

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IMPROVED MOTION DETECTOR AND COMPONENTS SUITABLE FOR USE THEREIN

FIELD OF THE INVENTION

The present invention is related to the field of motion detection and in particular to components useful *inter alia* in optical motion detectors as well as in other applications.

BACKGROUND OF THE INVENTION

Detection of transitions in signals are used in many detection applications.

One important application is in the detection of the motion of an optical mouse or other pointing devices. In some mouse systems, such as that described in PCT patent application PCT/IL99/00137, published as WO 99/46603, the disclosure of which is incorporated herein by reference, the motion is determined by the detection of zero-crossing of signals. In one preferred embodiment shown in that application, quadrature detection is used to determine the direction of motion, with the relative phase of the zero-crossings indicating the direction of motion and with the number of zero-crossings indicating a distance. The rate of the zero crossings can be used to indicate the velocity, if desired.

While in the above referenced application, the signals are derived from Doppler signals, in other applications in which zero-crossings are utilized to determine system parameters, edge detection or other phenomena are the source of the signals.

One problem with such systems is in a trade-off necessary between the light intensity used in such systems and the stability of the systems. In portable or wireless mouse systems, the use of minimal power is very desirable. On the other hand, the use of low light intensity results in noisy signals, which require that high amplification and low detection thresholds be used. This use results in apparent instability of the cursor or other indicators used in computer displays.

Fig. 1 shows a motion detector as described in the above referenced PCT application. In particular Fig. 1 is a reproduction of Fig. 17 of that application.

Fig. 1 shows a motion detector 500 that includes a source of partially coherent light 502 that illuminates a preferably collimating lens 504. Light that exits below lens 504 is preferably collimated (i.e., the rays are all parallel). A quarter wave birefringent plate 506 and a grating 508 underlay the plate. The light reflected/diffracted from the grating experiences a 180-degree phase shift between its orthogonal components due to its passing through the birefringent plate. While plate 506 are shown as separate elements, they may be combined into a single element, for example by depositing or embossing the grating on the surface of the birefringent plate.

A linear polarizer 510, preferably underlies the grating. Only one polarization of the light impinging on the polarizer passes through it, the rest (i.e., 50% of the energy) is absorbed. Light, that is reflected from a surface (not shown) underlying the polarizer will be circularly polarized after it passes through plate 506. However, since the light passes through polarizer 510 a second time before reaching plate 506, the polarization is enforced and "contamination" of the measurements is avoided. While this structure ensures that polarization is enforced, it reduces the light intensity illuminating the moving surface.

Light diffracted from the grating, at an angle determined by the grating line spacing, order of diffraction and the wavelength, and light diffusely reflected from the surface are incident on a detection module 512. Detection module 512 includes a phase grating 514 that splits the incident radiation into two preferably equal parts and sends them via a pair of polarizers 516 and 518 to a pair of detectors 520 and 522, respectively. Polarizers 516 and 518 are aligned at 90 degrees with respect to each other. Detection module 512 splits the circularly polarized wave (based on surface reflection) into linear components. Each of these components separately interferes with a portion of the wave diffracted by grating 508. The diffracted wave, having a linear polarization at 45 degrees to the direction of each of the polarizers, is also split by the grating and detected, preferably equally, by the detectors. The magnitude of the motion is determined from the number of zero crossings of the signals detected by the detectors (based on a Doppler shift between the light incident on the surface and the reflection detected by each detector separately). The direction of the motion is determined based on the relative phases of these signals.

Detection module 512 utilizes a phase grating and two polarizers to split and direct the incoming wave to the detectors. However, a polarizing beam splitter 524, such as shown in Fig. 2 (adapted from Fig. 3C of the above referenced application) can be used. In Fig. 2, polarizing beam splitter 524 is used to split the incoming waves and direct them to detectors 520 and 522.

An electronics module 526 controls source 502 and receives signals from detectors 520 and 522 and partially or fully processes the signals, as described in the application, to either determine the direction and magnitude of motion or to pass amplified signals to a processor for such determination.

Details of the determination of the direction and magnitude are described fully in the referenced application.

SUMMARY OF THE INVENTION

An aspect of some preferred embodiments of the invention is concerned with improvements in motion detectors.

An aspect of some preferred embodiments of the invention is concerned with improved optical components, suitable, inter alia, for use in motion detectors.

An aspect of some preferred embodiments of the invention is concerned with provision of a circuit having a variable hysteresis in the detection of signals. In a preferred embodiment of the invention, this device is utilized in a motion detector.

An aspect of some preferred embodiments of the invention is concerned with provision of a circuit having a variable threshold in the detection of signals. In a preferred embodiment of the invention, this device is utilized in a motion detector.

An aspect of some preferred embodiments of the invention is concerned with varying hysteresis or threshold in detection of a signal, dependent on the signal having a predetermined frequency.

An aspect of some preferred embodiments of the invention is concerned with the reduction of spurious signals in the detection of transitions in signals.

An aspect of some preferred embodiments of the invention is concerned with the provision of a reduced power optical mouse for a PC or the like.

An aspect of some preferred embodiments of the invention is concerned with a new type of polarizing beam splitter. In a preferred embodiment of the invention, this device is utilized in a motion detector.

An aspect of some preferred embodiments of the invention is concerned with a device which provides a circularly or elliptically polarized reflected or back-diffracted wave and which transfers a linearly polarized wave (or any wave of arbitrary polarization). In a preferred embodiment of the invention, this device is utilized in a motion detector.

An aspect of some preferred embodiments of the invention is concerned designing a device having arbitrarily determined polarization for reflected and transmitted waves, including linear, circular and arbitrary elliptical polarizations. Preferably, the transmitted wave is linearly polarized and the reflected wave is tailored to meet a substantially arbitrary specification.

There is thus provided, in accordance with a preferred embodiment of the invention, a polarizing beam splitter for radiation having a wavelength, comprising:

a series of first regions having a first effective index of refraction for a first polarization direction and a second effective index of refraction, different from the first index of refraction for a second polarization direction ; and

a series of second regions, interleaved with the regions of the first series of regions, said second regions having an effective index for at least one polarization direction different from that of the first regions for the same polarization direction.

Preferably, the first and second polarization directions are perpendicular to each other.

Preferably, the beam splitter is formed on or in a substrate. Preferably, the substrate is formed of a dielectric material. Alternatively, the substrate is formed of silicon. Preferably, the substrate is transparent to the radiation.

In a preferred embodiment of the invention, the series of first regions comprise sub-wavelength structure (SWS) formed on or in spaced portions of a surface of the substrate. Preferably, the first regions are formed on the surface. In a preferred embodiment of the invention, the second regions are formed of a different material from that of the substrate. Preferably, the second regions are formed of air.

In a preferred embodiment of the invention, the first regions are formed in the surface. Preferably, the second regions are formed of the same material as that of the substrate.

In a preferred embodiment of the invention, a wave with the first polarization direction passes through the surface and a wave with the second polarization direction passes through the surface.

Preferably, the distribution of energy among different diffraction directions is different from waves having the first and second polarizations. Preferably, the peak diffraction for the first and second polarizations is in different directions.

In a preferred embodiment of the invention, the radiation is back diffracted. Alternatively, the radiation is forward diffracted.

There is further provided, in accordance with a preferred embodiment of the invention, a multilayer optical structure comprising:

a first wave plate having a first difference in wavelength for a given wavelength;

a partially reflecting or diffracting layer underlying the first wave plate; and

a second wave plate, having a second difference in wavelength, for the given wavelength underlying the reflecting layer.

In a preferred embodiment of the invention, the partially reflecting or diffracting layer is a grating. Alternatively, the partially reflecting or diffracting layer is a partially reflecting layer.

In a preferred embodiment of the invention, the first difference in wavelength is $(2N+1)\lambda/8$, where N is a positive or negative integer or zero.

In a preferred embodiment of the invention, the second difference in wavelength is $(2M+1)\lambda/8$, where M is a positive or negative integer or zero.

In a preferred embodiment of the invention, the second difference in wavelength is $(2M+1)\lambda/8$, where M is a positive or negative integer or zero.

In a preferred embodiment of the invention, $N+M+1=4K$, where K is a positive or negative integer or zero.

In a preferred embodiment of the invention, a wave transmitted through the structure is linearly polarized.

Preferably, the wavelength is in the visible range. Alternatively, the wavelength is in the infra-red range.

There is further provided, in accordance with a preferred embodiment of the invention, a comparator system comprising:

an amplifier having a signal input and a signal output;

a first circuit, which, when connected as a feedback circuit on said amplifier provides a first amount of hysteresis to the comparator system;

a second circuit, which, when connected as a feedback circuit on said amplifier provides a second amount of hysteresis to the comparator system; and

a switch having a switching input, said switch being operative to switch feedback for the amplifier between said first and second circuits responsive to a signal at the switching input.

In a preferred embodiment of the invention, the amplifier is an operational amplifier.

In a preferred embodiment of the invention, the first and second circuits have common elements.

In a preferred embodiment of the invention, the comparator includes more than two feedback circuits selectively switchable to provide at least three levels of hysteresis.

Preferably, the comparator system comprises circuitry that, responsive to a characteristic of an output voltage of the comparator, provides a signal to the input of the switch to change the hysteresis of the comparator responsive to the characteristic.

In a preferred embodiment of the invention, the characteristic is a frequency of the output signal. Preferably, the hysteresis is reduced when the frequency of the output signal is above a given level.

In a preferred embodiment of the invention, the comparator system includes an input high pass filter that removes at least DC offset voltages at said signal input.

There is further provided, in accordance with a preferred embodiment of the invention, a quadrature detector system comprising:

a first input comprising a comparator system according to the invention;

a second input comprising a comparator system according to the invention; and

a quadrature detector.

There is further provided, in accordance with a preferred embodiment of the invention, a method of signal detection for a signal having an expected noise level comprising:

providing a system having variable hysteresis according to the invention;

wherein one of the amounts of hysteresis above the expected noise level and the other amount is below the expected noise level.

There is further provided, in accordance with a preferred embodiment of the invention, a method of signal detection for a signal having an expected noise level comprising:

providing a system having variable hysteresis according to the invention;

wherein both of the hysteresis amounts are above the expected noise level.

There is further provided, in accordance with a preferred embodiment of the invention, a variable threshold comparator system, comprising:

comparator circuitry having at least two inputs, including a signal input for a signal to be compared to a threshold and a threshold voltage input;

control circuitry that, responsive to a characteristic of an output signal of the comparator, provides a signal to the threshold voltage input of the comparator to change the threshold voltage thereof from a first threshold level to a second threshold level.

In a preferred embodiment of the invention, the characteristic is a frequency of the output signal. Preferably, said threshold is reduced when the frequency of the output signal is above a given level.

Preferably, said comparator has a hysteresis characteristic.

Preferably, the comparator includes circuitry that changes said hysteresis responsive to an output characteristic of the comparator.

Preferably, the comparator includes an input high pass filter that removes at least DC offset voltages at said signal input.

There is further provided, in accordance with a preferred embodiment of the invention, a quadrature detector system comprising:

a first input comprising a comparator having variable threshold according to the invention;

a second input comprising a comparator having variable threshold according to the invention; and

a quadrature detector.

There if further provided, in accordance with a preferred embodiment of the invention, a method of signal detection for a signal having an expected noise level comprising:

providing a system having variable threshold according to invention,

wherein one of the threshold levels is above the expected noise level and the other level is below the expected noise level.

There if further provided, in accordance with a preferred embodiment of the invention, a method of signal detection for a signal having an expected noise level comprising:

providing a system having variable threshold according to invention,

wherein both the threshold levels are above the expected noise level.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more clearly understood from the following description of the preferred embodiments thereof, taken together with the following drawings, in which the same or similar reference signs are used to indicate the same or similar elements:

Fig. 1 shows a motion detector of the prior art;

Fig. 2 shows a portion of an alternative polarizing quadrature detector of the prior art;

Fig. 3 is a schematic diagram of motion detection circuitry, in accordance with a preferred embodiment of the invention;

Figs. 4A and 4B are simplified transfer functions of comparators with hysteresis and threshold, respectively, in accordance with a preferred embodiment of the invention;

Figs. 5A and 5B show two variable hysteresis circuits, in accordance with a preferred embodiment of the invention;

Fig. 5C shows a variable threshold circuit, in accordance with a preferred embodiment of the invention;

Figs. 6A and 6B show two SWS beam splitters, in accordance with a preferred embodiment of the invention;

Fig. 7 shows a beam splitter according to Fig. 6A or 6B, in a motion detector, in accordance with a preferred embodiment of the invention; and

Fig. 8 shows an optical structure for producing a reflected wave of arbitrary polarization type and a transmitted linearly polarized wave, in accordance with a preferred embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

Fig. 3 shows a schematic of a detection system 8 according to a preferred embodiment of the invention. As described, circuit 8 is used in the circuit of Fig. 1 (or optionally with the optical detector of Fig. 2). However, the circuit shown in Fig. 3 has application to many other detection systems and the invention, except as specifically limited by the claims, is not limited to the present context. The circuit can also be used, for example in a speckle based motion detector, such as that described in US Patent 5,729,009 to Dandliker, et al, the disclosure of which is incorporated herein by reference.

In a preferred embodiment of the invention, the signals from detectors 520 and 522 are amplified by amplifiers 10 and 12 respectively. To remove possible DC bias of these signals, a pair of high-pass (or band pass) filters 20 and 22 are optionally, but not necessarily provided. A pair of variable hysteresis or variable threshold comparators 30 and 32, preferably of one of the types described below, provide analog to binary conversion as described below. In the variable hysteresis comparators, the zero crossings are each delayed in accordance with the amount of hysteresis provided by comparators 30 and 32. An idealized transfer function of one embodiment of comparators 30 and 32 is shown in Fig. 4A. Reference "h" is the amount of hysteresis. An idealized transfer function of variable threshold comparators 30 and 32 is shown in Fig. 4B. "t" is a variable and "h" is a preferably constant small hysteresis.

The outputs of comparators 30 and 32 are fed into a quadrature decoder 24, which determined the amount of the motion from the number of zero-crossings of the outputs of comparators 30 and 32, and its direction from the relative phases of the signals as known in the art of quadrature detection. A processor 26 receives signals indicative of the amount and direction of motion from quadrature decoder 24 (and optionally similar signals from a similar detector for a direction orthogonal to that determined by optical detectors 520 and 522) on lines 13 and 14 respectively, and sends a motion signal to a computer or other user of the information.

In the absence of the preferred embodiments of comparators 30 and 32, detection system 8 is subject to noise, which is especially troubling when there is no motion. In this situation, noise in the circuit causes spurious zero crossings. These zero crossings are translated into a jitter in the position of a cursor or other indicator on a computer screen.

In a simple embodiment, comparators have a fixed hysteresis or threshold. While this reduces or eliminates the jitter, it also reduces the accuracy of the measurement of the motion, since drop out (lost zero crossings) problems may result.

In a preferred embodiment of the invention, variable hysteresis comparators are used. The hysteresis of these comparators is controlled by a controller 28, based on a signal from processor 26 (or alternatively, from quad decoder 24). In a quiescent condition, the hysteresis h is high enough such that noise does not cause any level change from the comparators, but low enough such that actual motion does cause alternating level changes with high probability. However, when actual motion takes place, and processor 26 receives a signal, the hysteresis of comparators 30 and 32 is reduced, to increase the sensitivity of circuit 8 and reduce the drop-out probability. The lower hysteresis may be below or somewhat above the noise level.

In accordance with an alternative preferred embodiment of the invention, comparators 30 and 32 have a variable threshold. The threshold of these comparators is controlled by controller 28, based on a signal from processor 26 (or alternatively, from quad decoder 24). In a quiescent condition, the threshold t is high enough such that noise does not cause any level change from the comparators, but low enough such that actual motion does cause a level change. However, when actual motion takes place, and processor 26 receives a signal, the threshold of comparators 30 and 32 is reduced, to increase the sensitivity of circuit 8 and reduce the drop-out probability. The lower thresholds may be below or somewhat above the noise level.

It should be understood that a single channel circuit (i.e., only a single detector) with variable hysteresis or threshold would be applicable for noise suppression for a single detector.

Fig. 5A shows a preferred embodiment of comparator 30. Comparator 30 preferably comprises an operational amplifier 50, such as a TL081 operational amplifier, with its negative input grounded and with its positive input connected to a signal input via a relatively small resistor 52. The output of amplifier 50 is fed-back to the positive input, to provide positive feedback.

The feedback preferably comprises a fixed feedback resistor 54 and a variable feedback path 56. Variable feedback path 56 preferably comprises a resistor 58 that is relatively small compared to resistor 54 and a switch 60, that may be a transistor switch, or any other type of switch. The voltage at the positive terminal of the operational amplifier is substantially equal to the input signal and the logic output voltage times a feedback factor that is small when the switch is open and is large when the switch is closed (short circuited).

Consider a situation in which the input (and output) are positive. The positive output voltage is fed-back such that it keeps the comparator from switching unless the input becomes substantially negative. The amplitude of the negative voltage needed to switch the comparator is the factor "h" indicated in Fig. 4. When switch 60 is open the feedback resistance is high and the hysteresis is low. When the switch is closed, the feedback resistance is low and hysteresis is high. Switch 60 may be any suitable switch known in the art such as FET or BJT transistor switch circuits.

An alternate version of the hysteresis comparator is shown in Fig. 5B. Fig. 5B differs from that of Fig. 5A in that it includes a low pass filter 62 (for example, comprising a resistor 64 and a capacitor 66) which is operative to neutralize drifts and bias in the signal entering the comparator. In a preferred embodiment of the invention, when the comparator of Fig. 5B is used, band pass filters 20 and 22 may be omitted, in the circuit of Fig. 3. In one preferred embodiment of Fig. 5B, the lower terminal or resistor 64 is connected to the positive input of the amplifier. In another preferred embodiment of the invention, it is connected to the signal input point as indicated by the dashed line. The feedback circuit is connected to the positive input of the amplifier in both embodiments.

For a typical circuit as used in the device of Fig. 3 (for use in the motion detector of Fig. 1), resistor 52 is 1 kohm, resistor 64 is 1Mohm, capacitor 66 is 100 nF, resistor 54 is 5 Mohm, and resistor 58 is 500 kohm.

Fig. 5C shows a simple variable threshold circuit 65, in which controller 28 supplies a variable voltage (the variable threshold voltage, t) to the negative input of an op-amp 63. Feedback circuit 67 causes the device to operate as a comparator with a small hysteresis. In an idle condition (no detected motion) the threshold is substantially greater then the RMS noise in the signal. The asymmetry introduced into the curve is operative to avoid zero crossings being causes by the noise. When motion over a certain amount is detected, the threshold voltage is reduced, preferably to zero. It is noted that a small amount of hysteresis is present to suppress oscillations. This hysteresis is preferably similar to that of the circuits of Figs. 5A and 5B when motion has been detected.

In a preferred embodiment of the invention, controller 28 changes the states of these comparators when zero crossings above a predetermined rate (corresponding to a predetermined velocity of movement) is detected. Thus, the threshold and hysteresis can be considered to be controlled by the frequency of the output. Alternatively, more than two level or continuous

control of the threshold or hysteresis may be provided, for example, using a continuously variable threshold or feedback resistance, or both.

Fig. 6A shows a simplified cross-section of a sub-wavelength structure (SWS) type polarizing beam splitter 70, suitable for use as a beam splitter in the configurations shown in Figs. 7 and 1. However, beam splitter 70, while useful in the motion detectors of Figs. 1 and 7, is also useful in other applications requiring polarizing beam splitters.

Beam splitter 70 is preferably comprised of a base 72 of a dielectric material or silicon (for suitable wavelengths, such as IR) and a series of groups 74 of protrusions of height h and period d preferably formed of the same material. The period d is of the order of (but less than) the wavelength and the period D groups is chosen to provide a desired diffraction angle.

For closely spaced protrusions, the section with the protrusions has a different index of refraction for light having a polarization perpendicular to the protrusions and light having a polarization parallel to the protrusions. The indices are denoted by n1 for one polarization (p1) and n2 for the other (p2). When used as a reflective beam splitter, h is preferably such that $h \bullet n1 = m\lambda/2$ and $h \bullet n2 = (m+1/2)\lambda/2$, where m is a natural number. When used as a transmissive type beam splitter $h(n1-1)=m\lambda$ and $h(n2-1)=(m+1/2)\ \lambda$. In this way polarization p1 is diffracted mostly at zero order while polarization p2 is diffracted mostly at other orders. Preferably DE is chosen such that the field strength reflected at half wavelength phase cancels the field reflected from the etched out areas at zero order. Thus, extinction of the p2 polarization for the p1 direction can be achieved.

An inverse example of the beam splitter of Fig. 6A is shown in Fig. 6B. Similar principles apply.

Polarizing beam splitters of the type shown in Figs. 6A and 6B are compact and relatively insensitive to humidity, temperature, etc..

Fig. 7 shows a reflection type beam splitter 102, of the type shown in Fig. 6A or 6B, utilized in a motion detector 100 of the type shown in Fig. 3C of the above referenced PCT application. Detector 100 includes a source of illumination 105 including a collimating system which illuminates a structure 104 with at least partially coherent linearly polarized light. Structure 104 may be comprised of elements 506, 508 and 510 of Fig. 1. More preferably, the structure is of the type described below with respect to Fig. 8. Some of the light is diffracted toward a reflector/lens 106 which focuses the light onto detectors 108 and 110. Polarizing beam splitter 102 is oriented to split the diffracted beam into two, preferably. equal orthogonally

linearly polarized portions which are differentially diffracted to impinge as focused beams on detectors 108 and 110.

A portion of the light illuminating structure 104 passes through the structure and is diffusely reflected from an underlying moving surface 112. This light is also focused by reflector/lens 106 and split by beam splitter 102 so that it is focused on the detectors. The remainder of the operation is as described with respect to Fig. 1 and in the PCT application cited above.

A transmission type polarizing beam splitter can be used to replace all of the elements 512, 514, 516 and 518 of Fig. 1. Otherwise the operation of the detector is the same.

Fig. 8 shows a lower loss structure 80 for illuminating the moving surface underlying the device shown in Fig. 1. This structure replaces birefringent plate 506, grating 508 and polarizer 510 of Fig. 1. Unlike the corresponding structure of Fig. 1, structure 80 does not discard any of the light that is not reflected from the structure, apart from some absorption in the bulk of the material and light reflected from the surfaces. This reflection is preferably reduced by using anti-reflection coatings.

Structure 80 comprises an inner birefringent eighth-wave ($\lambda/8$) layer 82 overlying a partially reflective layer 84. Layer 84 overlies a three-eighths wave ($3\lambda/8$) layer 86, which in turn overlays a linear polarizing layer 88.

In operation, an incident linearly polarized wave is incident on layer 82. Part of the wave that passes through layer 82 is reflected from the reflective layer 84 and passes through layer 82 a second time. The reflected wave is thus transformed from linear polarization to circular polarization (as in the corresponding structure of the prior art).

The portion of the wave that passes through the partial reflecting layer 84 passes through $3\lambda/8$ layer 86. The total phase difference between the two polarizations of the wave is thus a half wave length and the wave is linearly polarized at a 90 degree angle to the original polarization. This linearly polarized wave passes, without loss, through polarizing layer 88. This linearly polarized wave is reflected from a surface 90, whose motion is being measured and again passes through the entire structure from the bottom up. Polarizing layer 88 removes contamination caused by depolarization of the wave by surface 90. Except for partial reflection from reflective layer 84 of the light reflected from surface 90, the entire structure is essentially lossless.

In general, to have a circular polarized reflected (local oscillator) wave, the retardation of layer 82 should be $R_{82}=(2N+1)\lambda/8$, where N is an integer or zero or negative. To turn the

elliptically polarized wave, that passes through layer 82 only once, into a linear polarized wave (which passes through layer 88 without loss), the retardation of layer 86 should also be $R_{86}=(2M+1)\lambda/8$, where M is an integer, which may be the same as, or different from N. However, to provide for the wave that passes through the structure to be linearly polarized, in the same direction as the incoming wave, N+M+1=4K, where K is a positive or negative integer or zero. Thus, if K is 0, either N or M can be -1 and the other is 0. Thus it is easily seen that reversing the layers 82 and 86 results in a completely equivalent structure.

It should be noted that either N or M (or both) may have negative. For this case, the negative number is realized by reversing the fast and slow axes of the wave plates.

It should be understood that while layer 84 is described as a partially reflective layer, it can, in fact be a diffractive layer, as described in the referenced PCT patent application.

It should be understood that, if N and/or M are not limited to integer values, the general structure 80 can be used to supply any type of elliptic (or linear) polarization of the wave reflected from layer 84 and any polarization for the wave transmitted past layer 86. Thus, if layer 88 is included in the structure, a lossless structure for providing linear polarization of a transmitted light is provided without any design limitations on the polarization of the reflected or diffracted wave. Furthermore, if layer 88 is deleted, a method for designing devices for providing arbitrarily chosen elliptic polarization for reflective and transmitted waves are easily provided. Even if N and M are limited to zero or integer values a variety of different transmitted and reflected polarizations can be achieved.

While structure 80 has been described in the context of a motion detector, it is clear that the extended principles described in the previous paragraph, are applicable to a large number of other applications as well.

It will be understood that a motion detector in accordance with preferred embodiments of the invention may include one or more of the improved polarizing beam splitter, hysteresis circuits and composite reflective part. Furthermore, while a number of different embodiments have been shown, details of one embodiment of the invention may, where applicable, be different in other embodiments. Similarly, some details shown in the embodiments, while preferred, are not essential and some preferred embodiments of the invention may omit them. While application of some of the novel components of the present invention have been described as being used with certain embodiments of the referenced PCT application, these are only examples of their use and they may be used with others of the embodiments shown in the PCT application as well as with other types of motion detectors.

As used herein, the terms "have", "include" and "comprise" or their conjugates, as used herein mean "including but not limited to".

CLAIMS

1. A polarizing beam splitter for radiation having a wavelength, comprising:

a series of first regions having a first effective index of refraction for a first polarization direction and a second effective index of refraction, different from the first index of refraction for a second polarization direction; and

a series of second regions, interleaved with the regions of the first series of regions, said second regions having an effective index for at least one polarization direction different from that of the first regions for the same polarization direction.

2. A beam splitter according to claim 1 wherein the first and second polarization directions are perpendicular to each other.

3. A beam splitter according to claim 1 or claim 2 formed on or in a substrate.

4. A beam splitter according to claim 3 wherein the substrate is formed of a dielectric material.

5. A beam splitter according to claim 3 or claim 4 wherein the substrate is formed of silicon.

6. A beam splitter according to any of claims 3-5 wherein the substrate is transparent to the radiation.

7. A beam splitter according to any of claims 3-6 wherein the series of first regions comprise sub-wavelength structure (SWS) formed on or in spaced portions of a surface of the substrate.

8. A beam splitter according to claim 7 wherein the first regions are formed on the surface.

9. A beam splitter according to claim 8 wherein the second regions are formed of a different material from that of the substrate.

10. A beam splitter according to claim 9 wherein the second regions are formed of air.

11. A beam splitter according to claim 7 wherein the first regions are formed in the surface.

12. A beam splitter according to claim 11 wherein the second regions are formed of the same material as that of the substrate.

13. A beam splitter according to any of the preceding claims wherein a wave with the first polarization direction passes through the surface and a wave with the second polarization direction passes through the surface.

14. A beam splitter according to any of the preceding claims wherein the distribution of energy among different diffraction directions is different from waves having the first and second polarizations.

15. A beam splitter according to claim 14 wherein peak diffraction for the first and second polarizations is in different directions.

16. A beam splitter according to any of the preceding claims, wherein the radiation is back diffracted.

17. A beam splitter according to any of claims 1-15, wherein the radiation is forward diffracted.

18. A multilayer optical structure comprising:

a first wave plate having a first difference in wavelength for a given wavelength;

a partially reflecting or diffracting layer underlying the first wave plate; and

a second wave plate, having a second difference in wavelength, for the given wavelength, underlying the reflecting layer.

19. A multilayer structure according to claim 18 wherein the partially reflecting or diffracting layer is a grating.

20. A multilayer structure according to claim 18 wherein the partially reflecting or diffracting layer is a partially reflecting layer.

21. A multilayer structure according to any of claims 18-20 wherein the first difference in wavelength is $(2N+1)\lambda/8$, where N is a positive or negative integer or zero.

22. A multilayer structure according to any of claims 18-20 wherein the second difference in wavelength is $(2M+1)\lambda/8$, where M is a positive or negative integer or zero.

23. A multilayer structure according to claim 21 wherein the second difference in wavelength is $(2M+1)\lambda/8$, where M is a positive or negative integer or zero.

24. A multilayer structure according to claim 23 wherein $N+M+1=4K$, where K is a positive or negative integer or zero.

25. A multilayer structure according to any of claims 18-24 wherein a wave transmitted through the structure is linearly polarized.

26. A multilayer structure according to any of the preceding claims wherein the wavelength is in the visible range.

27. A beam splitter according to any of claims 1-25 wherein the wavelength is in the infra-red range.

28. A comparator system comprising:

an amplifier having a signal input and a signal output;

a first circuit, which, when connected as a feedback circuit on said amplifier provides a first amount of hysteresis to the comparator system;

a second circuit, which, when connected as a feedback circuit on said amplifier provides a second amount of hysteresis to the comparator system; and

a switch having a switching input, said switch being operative to switch feedback for the amplifier between said first and second circuits responsive to a signal at the switching input.

29. A comparator according to claim 28 wherein the amplifier is an operational amplifier.

30. A comparator according to claim 28 or claim 29 wherein the first and second circuits have common elements.

31. A comparator system according to any of claims 28-30 having more than two feedback circuits selectively switchable to provide at least three levels of hysteresis.

32. A comparator system according to any of claims 28-31 and including:

circuitry that, responsive to a characteristic of an output voltage of the comparator, provides a signal to the input of the switch to change the hysteresis of the comparator responsive to the characteristic.

33. A comparator system according to any of claims 28-32, wherein the characteristic is a frequency of the output signal.

34. A comparator system according to claim 33 wherein said hysteresis is reduced when the frequency of the output signal is above a given level.

35. A comparator system according to any of claims 28-34 and including an input high pass filter that removes at least DC offset voltages at said signal input.

36. A quadrature detector system comprising:

a first input comprising a comparator system according to any of claims 28-35;

a second input comprising a comparator system according to any of claims 28-35; and

a quadrature detector.

37. A method of signal detection for a signal having an expected noise level comprising:

providing a system according to any of claims 28-36;

wherein one of the amounts of hysteresis is above the expected noise level and the other amount is below the expected noise level.

38. A method of signal detection for a signal having an expected noise level comprising:

providing a system according to any of claims 28-36,
wherein both of the hysteresis amounts are above the expected noise level.

39. A variable threshold comparator system, comprising:
comparator circuitry having at least two inputs, including a signal input for a signal to be compared to a threshold and a threshold voltage input; and
control circuitry that, responsive to a characteristic of an output signal of the comparator, provides a signal to the threshold voltage input of the comparator to change the threshold voltage thereof from a first threshold level to a second threshold level.

40. A comparator system according to claim 39, wherein the characteristic is a frequency of the output signal.

41. A comparator system according to claim 40 wherein said threshold is reduced when the frequency of the output signal is above a given level.

42. A comparator system according to any of claims 39-41 wherein said comparator has a hysteresis characteristic.

43. A comparator system according to claim 42 including circuitry that changes said hysteresis responsive to an output characteristic of the comparator.

44. A comparator system according to any of claims 39-43 and including an input high pass filter that removes at least DC offset voltages at said signal input.

45. A quadrature detector system comprising:
a first input comprising a comparator according to any of claims 39-44;
a second input comprising a comparator according to any of claims 39-44; and
a quadrature detector.

46. A method of signal detection for a signal having an expected noise level comprising:
providing a system according to any of claims 39-45,

wherein one of the threshold levels is above the expected noise level and the other level is below the expected noise level.

47. A method of signal detection for a signal having an expected noise level comprising: providing a system according to any of claims 39-45,

wherein both the threshold levels are above the expected noise level.

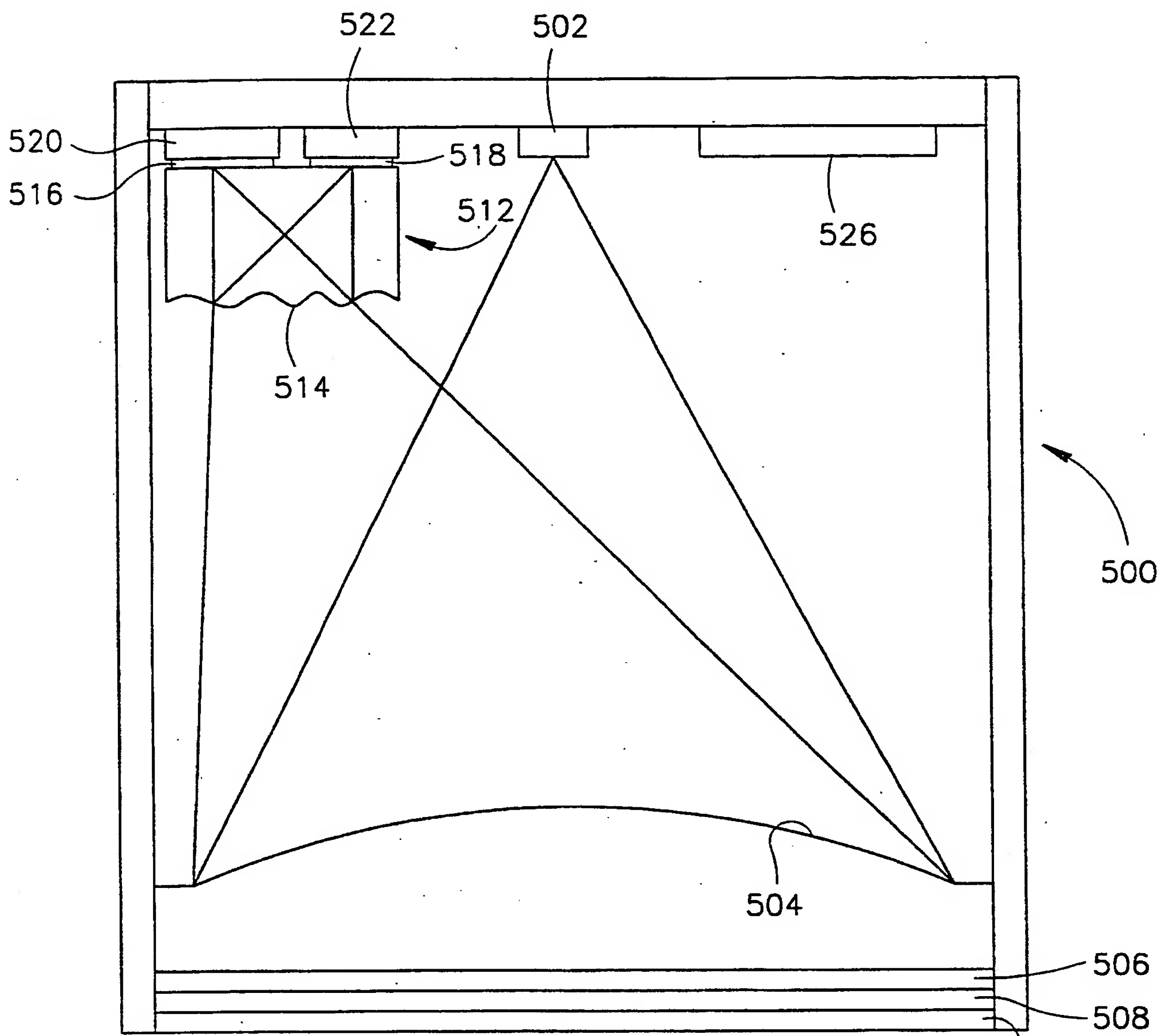

FIG.1

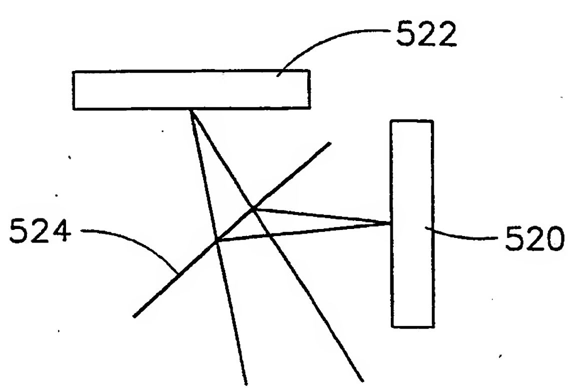

FIG.2

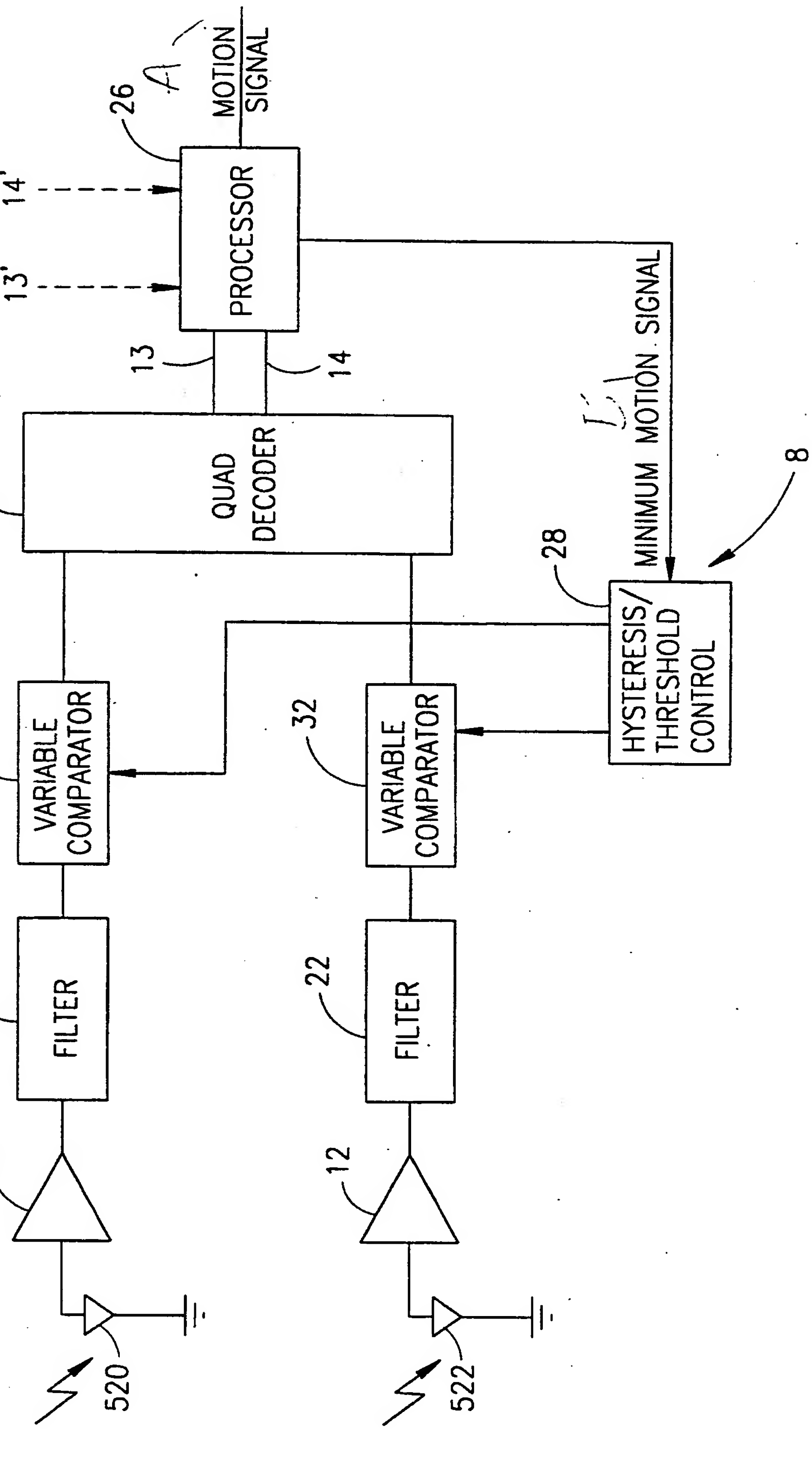
MOTION SIGNAL
26
PROCESSOR
14'
13'
13
14
QUAD DECODER
24
MINIMUM MOTION SIGNAL
8
28
HYSTERESIS/ THRESHOLD CONTROL
VARIABLE COMPARATOR
30
VARIABLE COMPARATOR
32
FILTER
20
FILTER
22
10
12
520
522

FIG.3

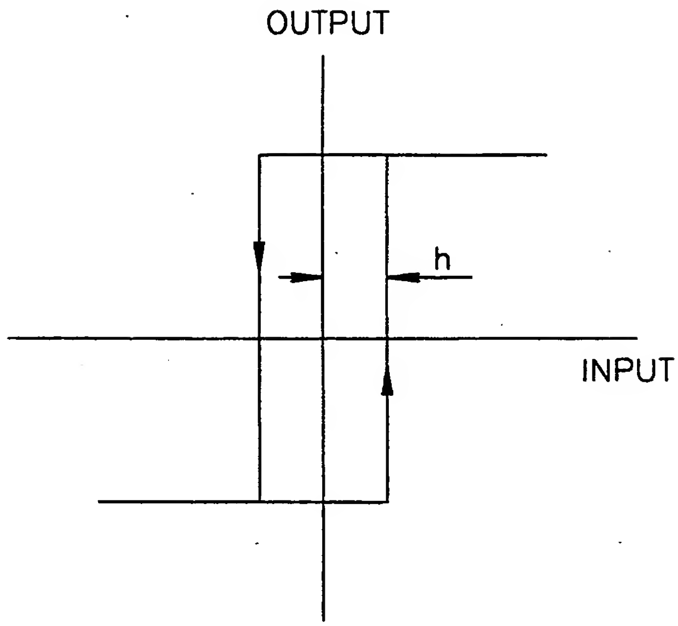

FIG.4A

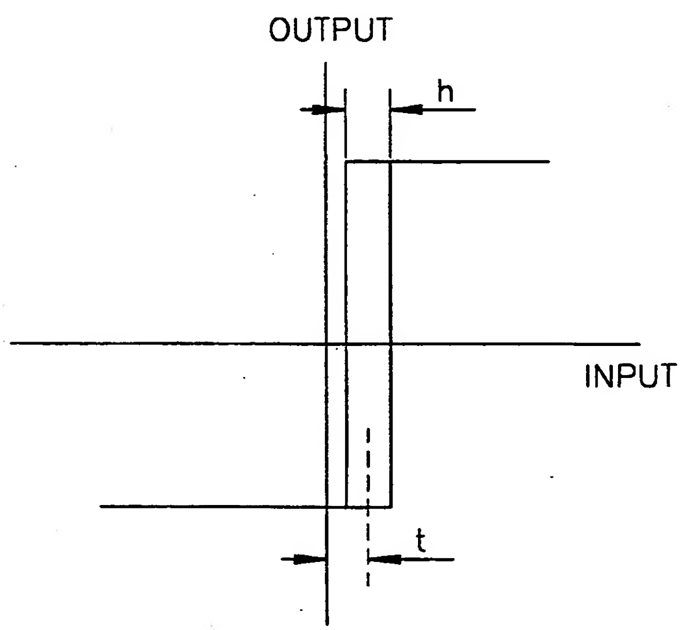

FIG.4B

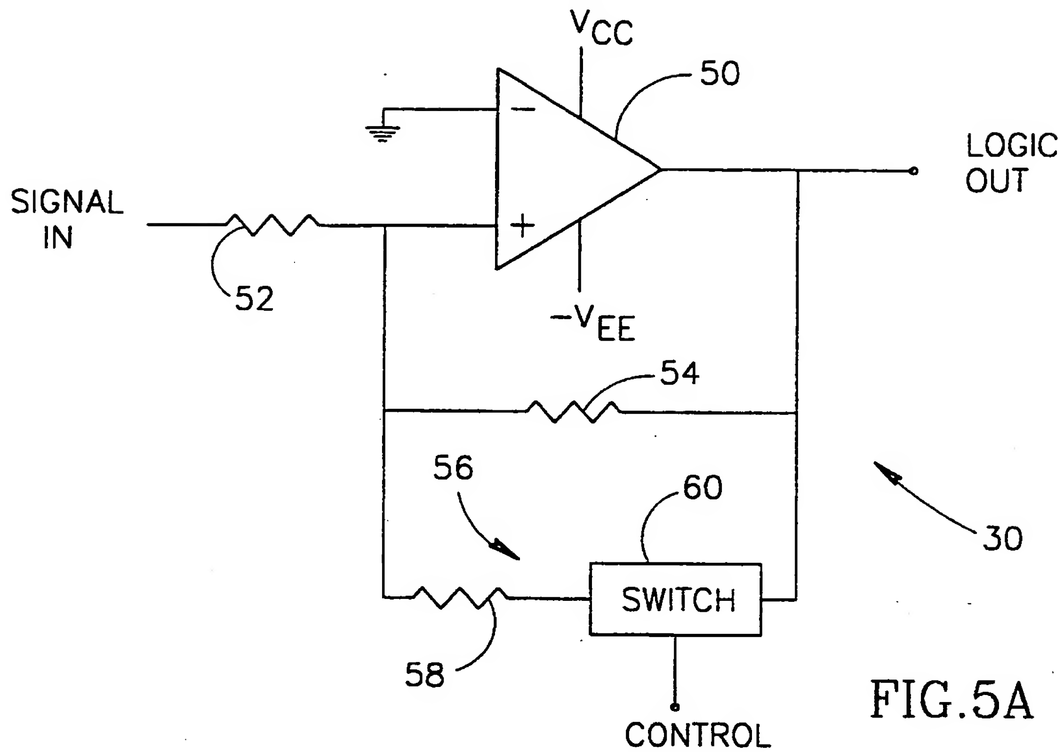
VCC
50
LOGIC
OUT
SIGNAL
IN
52
-VEE
54
56
60
30
SWITCH
58
CONTROL

FIG.5A

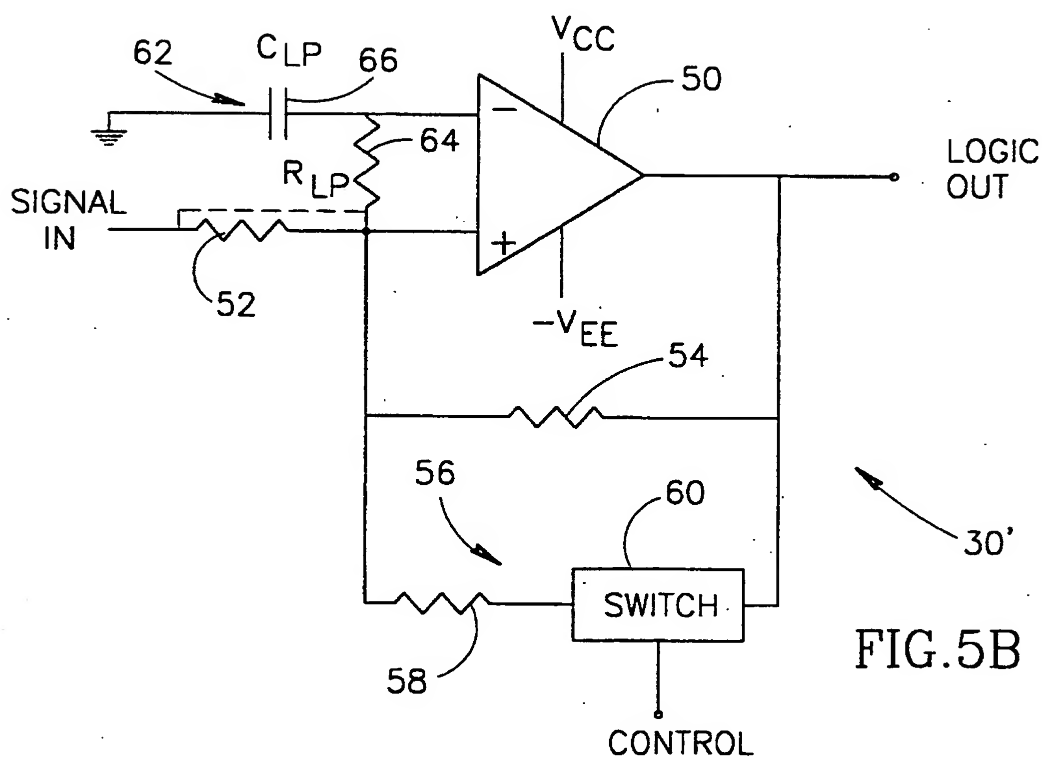
62
CLP
66
VCC
50
64
RLP
LOGIC
OUT
SIGNAL
IN
52
-VEE
54
56
60
30'
SWITCH
58
CONTROL

FIG.5B

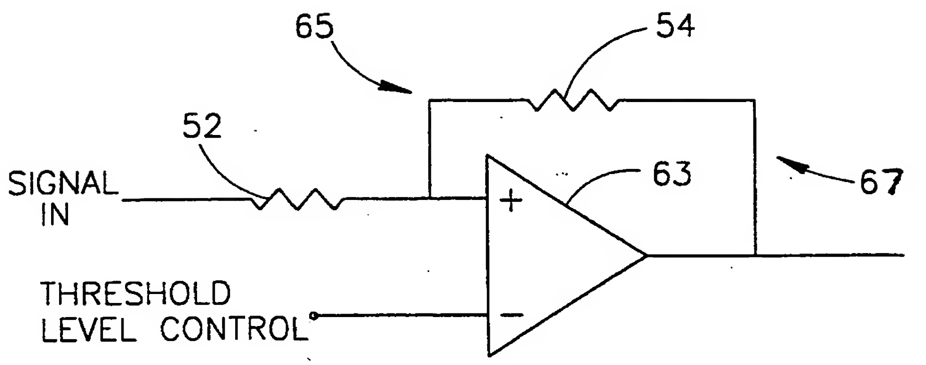

FIG.5C

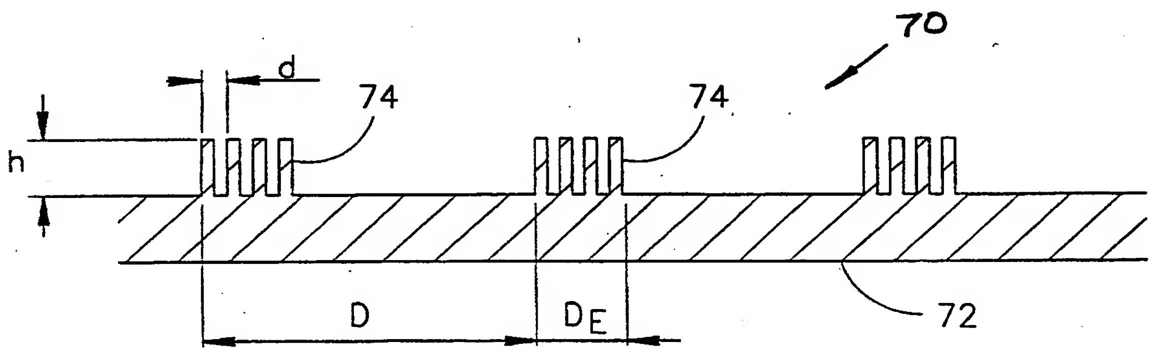

FIG.6A

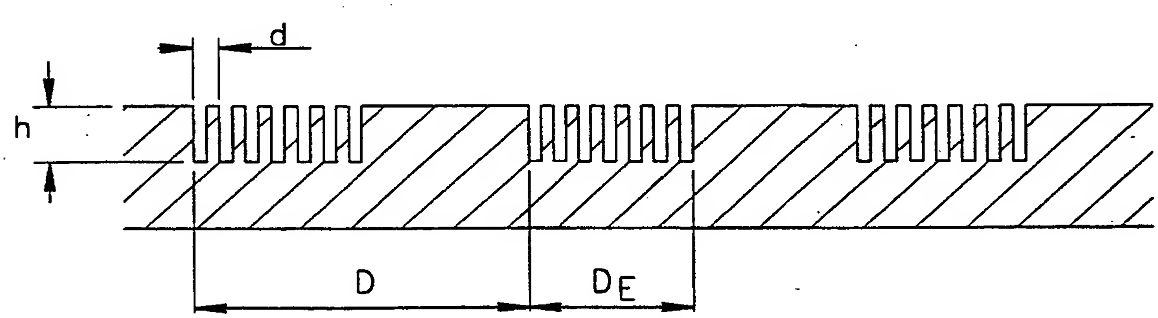

FIG.6B

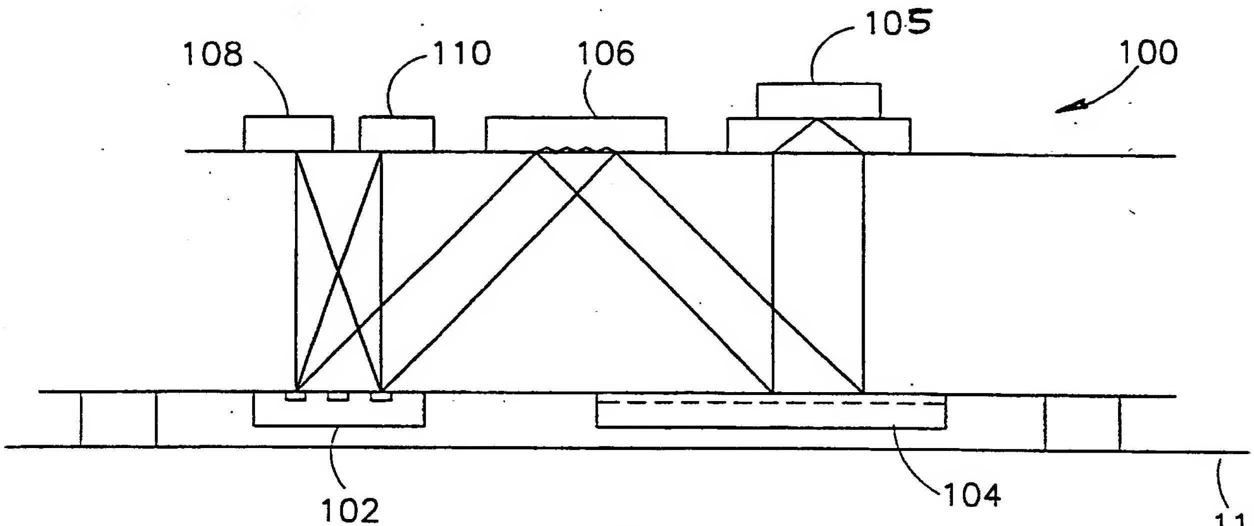

FIG.7

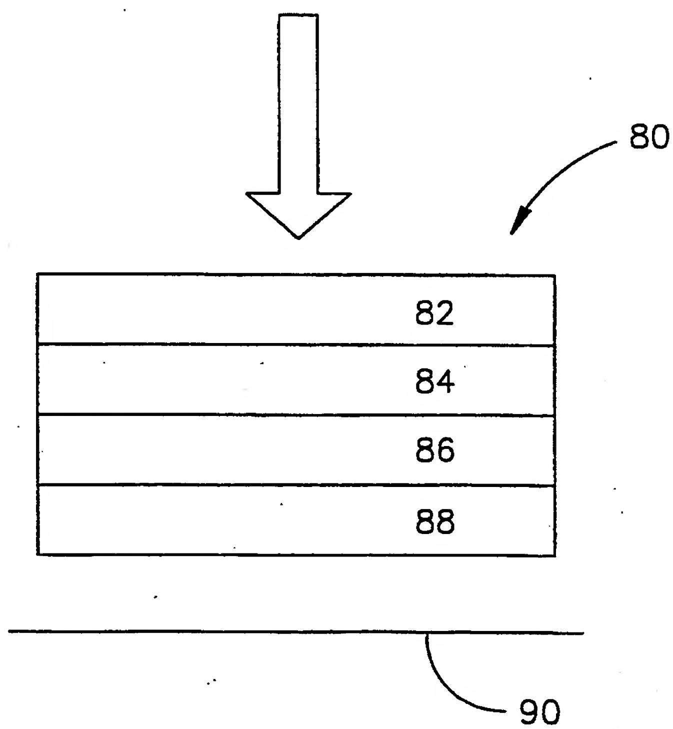

FIG.8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 99/00669

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B5/18 G02B5/30 G06K11/18 H03K5/08 H03K3/0233

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G06K H03K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 014, no. 148 (P-1024), 20 March 1990 (1990-03-20) -& JP 02 008802 A (NEC CORP), 12 January 1990 (1990-01-12) abstract; figures	1-17
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X	US 5 548 422 A (CONNER ARLIE ET AL) 20 August 1996 (1996-08-20) column 15, line 4 - line 39; figure 10	18,20, 25,26

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 December 2000	28 DEC 2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ward, S

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 424 949 A (HUGHES AIRCRAFT CO) 2 May 1991 (1991-05-02) column 5, line 17 – line 20; figure 3	18,19,26
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X A	EP 0 365 401 A (TELEDIFFUSION FSE) 25 April 1990 (1990-04-25) column 3, line 40 -column 5, line 19 column 4, line 42 – line 58 figures 3-5	39,42, 43,46,47 28
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A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 08, 30 June 1998 (1998-06-30) -& JP 10 069673 A (ASAHI GLASS CO LTD), 10 March 1998 (1998-03-10) abstract; figures	1-17

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Intern. ial Application No
PCT/IL 99/00669

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	SCHMITZ M ET AL: "GRATINGS IN THE RESONANCE DOMAIN AS POLARIZING BEAM SPLITTERS" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 20, no. 17, 1 September 1995 (1995-09-01), pages 1830-1831, XP000520908 ISSN: 0146-9592 the whole document	1-17
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A	US 5 986 224 A (KENT JOEL) 16 November 1999 (1999-11-16) abstract column 33, line 15 -column 40, line 56 column 34, line 20 - line 36	28, 37-39, 46,47
A	EP 0 423 731 A (MATSUSHITA ELECTRIC IND CO LTD) 24 April 1991 (1991-04-24) abstract; figure 1	30
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INTERNATIONAL SEARCH REPORT	International application No. PCT/IL 99/00669

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-17,27

   Polarising beamsplitter

2. Claims: 18-26

   Multilayer optical structure

3. Claims: 28-47

   Comparator system

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 99/00669

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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Form PCT/ISA/210 (patent family annex) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 99/00669

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